COMMISSIONING WITH BEAM: SESSION SUMMARY

M. Lamont, CERN, Geneva, Switzerland

INTRODUCTION

The aims of the session were to:

- Establish an overall strategy for commissioning with beam which places emphasis on careful preparation and staging the beam related goals of the commissioning and thus stages the demands on the commissioning of the various sub-systems.
- Provide an initial breakdown of the operational phases needed to reach the goal of establishing first collisions. For each phase clearly delineated entry and exit conditions are stated along with well-defined set of requisites
- Detail the available beam instrumentation, and its commissioning needs, during the early stages of commissioning.

OVERALL STRATEGY

Preparation

The importance of thorough preparation to effective beam commissioning was stressed.

The lead up to commissioning with beam sees the end of hardware commissioning, an extended machine checkout phase, the re-commissioning of TI8 and the commissioning of TI2. The exit conditions from each of these needs to be defined, and in particular the goals and a detailed planning for the machine checkout phase should be established.

Optimisation of the pre-beam period is clearly possible by appropriate parallelism.

Commissioning with beam

The need for a staged approach was emphasised and the key goals of the stage one were identified as: establishing colliding beams as quickly as possible; safely; without compromising further progress.

The aim of the first stage is to take two moderate intensity multi-bunch beams to high energy and collide them. Specifically 43 on 43 bunches with 3 to 4 x 10^{10} protons per bunch at 7 TeV is foreseen. Initial collisions will be un-squeezed. This moderate target simplifies things for a number of reasons detailed in the session.

A staged approach allows one to commission the equipment, the beam instrumentation and the machine protection system to the levels required and to optimise the commissioning path needed to achieve the above objectives.

The potential advantages of the sector test as a pre-cursor were re-iterated.

Phases

The commissioning phases required to reach the Stage 1 goals were enumerated:

1	Transfer and Injection
2	First turn
3	Circulating beam
4	450 GeV: initial commissioning
5	450 GeV: consolidation
6	450 GeV: two beam operation
7	Switch to Nominal cycle
8	Snapback – single beam
9	Ramp – single beam
10	Single beam to physics energy
11	Two beams to physics energy
12	Physics – un-squeezed
13	Commission squeeze – single beam
14	Physics – partial squeeze

At each phase, in general, the following will be required:

- Equipment commissioning with beam
- Instrumentation commissioning
- Checks with beam: BPM Polarity, corrector polarity, BPM response
- Machine protection
- Beam measurements: beam parameter adjustment, energy, linear optics checks, aperture etc. etc.

Prerequisites and exit conditions for each phase were given.

Machine Protection

Machine Protection System (MPS) commissioning with beam will be a piece-wise, iterative process. It is clear we need a well defined plan for the commissioning and integration of the MPS at each stage and phase of beam commissioning. This should include a full specification and formal acceptance procedures. To reiterate it is imperative that there is a well-defined plan of how to commission the MPS with beam with the aim of providing an appropriate level of protection at each commissioning stage.

TRANSFER AND INJECTION

The objectives of this phase were clearly delineated: the aims being to minimise the commissioning time and its impact; to make sure that it is done safely; and to deliver the required beam quality as required. Exit from this phase will see the beam injected on-axis through the TDI.

Preparation

System commissioning shall cover:

- Hardware: including transfer line magnets, dump and collimators. The kickers, septa and

protection devices, and the associated LHC magnets (warm and cold).
- Machine Protection. The hardware components of the machine protection system and the links between the hardware which link into it. The importance of this was again stressed.
- Beam Instrumentation
- Controls and software: application software, dedicated injection application software, expert applications. Plus dedicated software for injection commissioning

A breakdown of each of the phases of commissioning with beam was detailed:

1. First part if the transfer lines: SPS to down stream TED.
2. Last part of the transfer line, into the LHC, up to the TED.
3. Through the TED through D1 into the LHC.

These would be followed in due time by a staged increase in the intensity with associated implications for the machine protection system and performance issues.

Issues

The commissioning of TI2 and IR2 hardware commissioning and the associated checkout will be necessarily "just in time". Clearly careful planning is required here.

TI should be kept "operational" in 2006 to minimise the re-commissioning required in 2007.

450 GEV

450 GeV: Initial

The prerequisites for this phase were defined. The aim: to have the simplest possible machine, commissioning optics and the de-Gauss cycle in place. The lower intensities give allow more tolerance on the beam parameter variation; the commissioning tunes allow more coupling; and the lack of bumps and crossing angle give more aperture.

Progress naturally follows via:

- threading the first turn,
- closure,
- RF capture.

With each of these steps are associated needs for instrumentation, hardware adjustment and correction procedures. Having established circulating beam, the requisite beam instrumentation needs to be commissioned, coupled with beam parameter adjustment and first pass optics and aperture measurements.

450 GeV: Consolidation

The aim of this phase is to deliver a well adjusted 450 GeV machine with the MPS fully tested, approved and operational to take beam into the ramp. Measurements will include: linear optics checks and correction; beta beating, emittance, non-linear optics checks including the use of systematic bumps around the machine to explore the aperture and kicks to check the response of correctors and BPMs.

Equipment to be commissioning as far as necessary: collimators, RF, longitudinal feedback, and transverse feedback. Further commissioning of beam instrumentation, in particular the BLMs and the linking of them to the MPS takes place in this phase.

Two beams

When both rings have been separately commissioned, it will necessary to inject counter rotating beams bringing on the separation bumps and making beam parameter adjustments as required.

DE-GAUSS VERSUS NOMINAL

There is the option to perform the commissioning outlined thus far on the so-call de-Gauss cycle [1]. This cycle has the potential advantages:

- It effectively zeros persistent current at 450 GeV.
- The magnetic machine is relatively stable in time.
- There is no dependency on the powering history of the magnets.
- b5 could be expected to be approximately zero [2].

A full snapback rules this cycle out for the ramp and so the switch to the nominal cycle must be made before acceleration. Once the switch to the nominal cycle is made magnetic stability will be achieved by waiting 30 minutes allowing 30 to 40% decay of the total persistent currents to take place.

By using the de-Gauss cycle one might be able to get a handle on geometric and persistent current amplitudes by the comparison between the two cycles. Additionally there is no 30 minutes wait; a small consideration, perhaps, given the long re-cycle time and the likely frequency with which this will be performed.

However it has been argued that by using the de-Gauss cycle time is spent commissioning a cycle we can't use operationally. For one thing the b1 will be different on the nominal cycle implying a need to re-adjust the RF. Additionally the b7 will be larger on the de-Gauss cycle with possible implications for the dynamic aperture [2].

The issue needs to be examined in detail and a decision on whether or when to use the de-Gauss cycle should be taken in 2005.

SNAPBACK & THE RAMP

The procedure for snapback and ramping was detailed. The LHC baseline ramp will be used. The mechanics of ramping the power converters (including their real-time capabilities), the RF, the dump and the role of the timing system were described.

Prerequisites include:

- Beam Instrumentation
  - PLL if at all possible
  - Q' measurement of some sort
  - Orbit acquistion
- RMS: predictions of snapback, transfer functions, static errors…

- MPS: starts to be critical when ramping beyond snapback.
- Controls: including function generation and management, sequencer, timing. Run-to-run feed forward capabilities.
- RF beam control: phase, synchro and radial loops operational.

Ramp commissioning will necessarily be staged:

- Ramp – single beam, ring 1.
- Stop in ramp. Commission beam dump, machine protection in ramp, ring 1.
- Single beam to 7 TeV, ring 1 (± separation bump).
- Ramp – single beam, ring 2.
- Stop in ramp. Commission beam dump, machine protection in the ramp, ring 2.
- Single beam to 7 TeV, ring 2 (± separation bump).
- Two beams to 7 TeV, collide un-squeezed.

During commissioning some important, potentially time consuming studies will need to be performed. These include: power converter tracking, beam dump commissioning and BLM threshold adjustment

Stop in the ramp & variations

The ability to stop at a predestined place in the ramp will be provided. Equivalently functionality will be required for the squeeze. The usefulness of utilising this ability in the ramp was questioned: would the uncertainty in the nature of the magnetic machine negate the usefulness of any possible measurements?

SQUEEZE

The key issues during the squeeze are: the separation between beams; the aperture; and the need to drive the power converters smoothly avoiding zero crossing where possible and, if possible, low gradients in the insertion quadrupoles.

There are tight tolerances on gradient errors and the given limits on tune, beta beating, dispersion, and orbit mean excellent beam control is required: feedback will be desirable.

The time to squeeze is given by power converter ramp rates and is estimated to be about 8.5 minutes per IP plus round off and collimator adjustments.

Commissioning of the squeeze will take place with single beam. It's clear that that only partial squeezing will be attempted in the early stages. It is proposed to commission by squeezing one IR at a time, moving to squeezing IRs in parallel when understanding and control have been established.

An outline of the procedure was given. The primary and secondary collimators (and TCDQ) will have to follow the squeeze, with relaxed settings in the commissioning stage. Monitoring of key beam parameters will be necessary throughout. Clearly optics checks, aperture checks etc. will be necessary at each stage.

Issues

The accuracy with which the insertion quadrupole transfer functions are known and the understanding of the magnetic behaviour at low gradients given the preceding machine history and the reproducibility of this behaviour will be vital for control during the squeeze.

BEAM INSTRUMENTATION

Operative beam instrumentation is vital to the commissioning effort. Experience gained at LEP showed that a reduced dependence on the Beam Synchronous Timing (BST) would clearly be beneficial at start-up. This lesson has been assimilated into the design of LHC instrumentation.

A summary of availability in the early stages of commissioning was presented, summarised briefly here:

BPMs: On Day 0 orbit acquisition on pilot should be available immediately. Turn by turn data will be available when the BST has been commissioned. The BST will be timed in as soon as possible after the arrival of beam. As described above there will be systematic checks for polarity errors etc. with beam, with a systematic study of the performance over the long term.

BLMs: On Day 0 the "slow" monitors will be available immediately with the BST required for fast loss monitors. Calibration of the monitors and the effects of cross talk between the beams will required dedicated beam time. The setting of the thresholds for machine protection will require considerable effort.

BCT: On Day 0 the DC current measurement will be available immediately; bunch to bunch measurements wait on the BST. With low intensities, lifetime calculation will be slow.

Tune: On Day 0 the kick/FFT method can be used with multi- FFT available given application development. A PLL should be available within a few weeks.

Chromaticity: On Day 0 the Kick/Head-tail should work given the BST, as will the classical tune shift versus RF frequency shift method. Periodic momentum modulation will be possible when the PLL is available.

Coupling: On Day 0 it will be possible to look at the kick/beam response. The closest tune approach will be optimal when the PLL is available.

There is a clear need to get the BST and PLL working as soon as possible. However a healthy set of the basics should be available from the start.

Also stressed in this session was the need for high level application software to support the above instruments. System commissioners will be required to push the various systems fully into operations.

CONCLUSIONS

A breakdown of the strategy for, and the phases of, the initial beam commissioning of the LHC has been established. Over the coming months this needs to be elaborated with a detailed and comprehensive planning for all phases including the preparation. Documentation of developments will be available at [3].

A selection of issues arising from the session includes:

- Planning for MPS commissioning with beam is required.
- Scheduling of TI2 and IR2 commissioning.
- Keeping TI8 operational in 2006.
- The use of the de-Gauss cycle.
- Requirements for power converter tracking test with beam.
- Transfer functions of insertion quadrupoles. These need to be measured with some accuracy. Associated is the need for tools for measuring beta beating and identifying its sources.
- The strategy for the development of application software needs to be made clear.

ACKNOWLEDGEMENTS

Many thanks to the speakers in this session (Brennan Goddard, Paul Collier, Andy Butterworth, Oliver Brüning and Hermann Schmickler) for their well-prepared and well-focused presentations. I am obliged to Eugenia Hatziangeli for acting as scientific secretary and her help in preparing the session.

Thanks also to Oliver Brüning, Stephane Fartoukh and Jean-Pierre Koutchouk for their input on the de-Gauss cycle debate.

REFERENCES

[1] L. Bottura, “Superconducting Magnets on Day 1”, XIth Chamonix workshop on LHC performance, 2001.

[2] Stephane Fartoukh, private communication.

[3] LHC commissioning website: http://cern.ch/lhc-commissioning/